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Archeoseismicity and environmental crises at the Sialk Mounds, Central Iranian Plateau, since the Early Neolithic

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ABSTRACT

During the long-lasting cultural sequences of the Shurābeh and Sialk archeological mounds (6200–550 BC) the inhabitants encountered numerous diversified crises along a narrow fertile passageway at the edge of the Central Iranian Plateau Great Desert. Some of the threats may be attributed to earthquakes, drastic climatic changes, and man-made environmental deterioration, which possibly led to the settlement withdrawing at different stages toward a more suitable location. Our study identified the occurrence of a large-magnitude earthquake around 3800 BC along the Kāshān fault, which is well-documented by various lines of circumstantial evidence, including: (i) numerous contemporaneous smashed skeletons and artifacts underneath collapsed walls and ceiling debris in several different areas; (ii) tilted and collapsed walls; (iii) nearly N–S oriented fallen large storage jars; and (iv) nearly vertical deep ground fractures cutting walls and floors of the Sialk III_5 South Mound settlement. Archeological data also shows additional stratigraphic discontinuities and damages that may be attributed to earthquakes. However, damage features in limited exposed trenches are less conclusive and require additional careful excavations. Apparent ancient paleo-architectural innovative attempts to enhance the coherency/elasticity of the structures and minimize earthquake damage to buildings were also noted, suggesting the indigenous earthquake hazard mitigation endeavor. There seems to be a correlation between some site abandonment dates and possible drastic regional draught/cooling events. The natural and anthropogenic impacts addressed in this study constituted major threats to the sensitive archeological settlements at the fringe of the desert and the vicinity of the Kāshān active fault since antiquity.

1. Introduction

The *Sialk* archeological site (Ghirshman, 1938) is one of the oldest and long-lasting human settlements in the Central Iranian Plateau that was permanently settled by farming and metallurgical human communities. It comprises two mounds (North and South) separated by a distance of about 600 m, and two nearby cemeteries 'A' and 'B', located approximately 3 km southwest of the city of Kāshān (Fig. 1). The city was destroyed by the 1755 and 1778 earthquakes during reactivation of the adjacent Kāshān fault (Berberian, 1976, 1981, 1994).

The Sialk Mounds are located at the western fringes of the Central Iranian Great Desert, and the eastern foot of the lofty *Karkas Mountains* which has the highest peak of +3895 m. Flanked by two important geographic barriers to the east and the west, the Sialk Mounds are positioned on an important ancient trade route parallel to the Kāshān fault line (Fig. 1).

The ca. 6000–4300 BC 'Sialk North Mound', covering an area of ~320 × 110 m, is smaller and older than the ca. 4100–550 BC 'Sialk South Mound', which covers an area of ~260 × 190 m (Fig. 1). The elevation of the plain in between the two mounds ranges from about +944 m (surrounding the North Mound) to +950 m (surrounding the South Mound). The sterile soil was reached at elevations of +937.59 m and +946.14 m, at the North and the South

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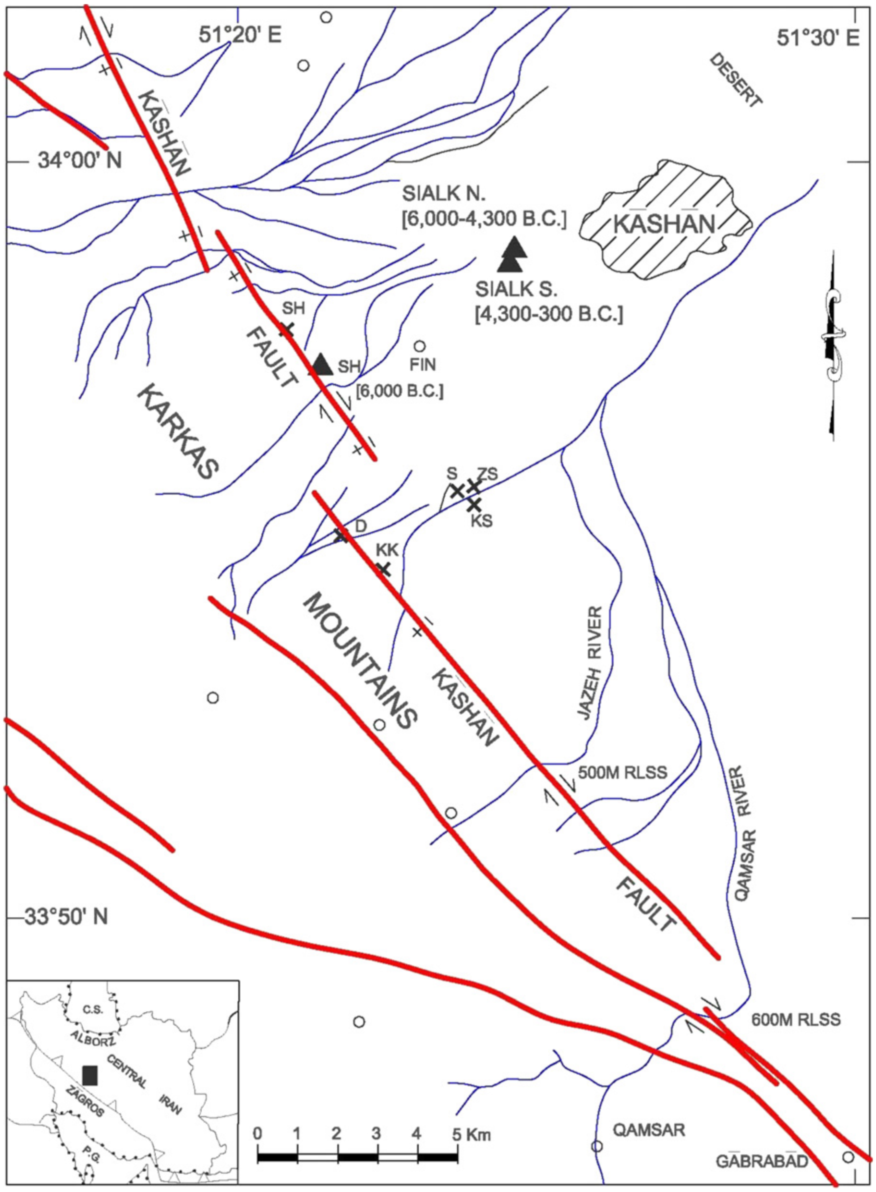

Fig. 1. Location of the Sialk north and south, and the Shurābeh (SH) archeological mounds (filled triangles) in between the city of Kāshān (destroyed during the 1755 and 1778 earthquakes) and the Kāshān right-lateral strike-slip fault. The Kāshān active fault is located to the northeastern foot of the Karkas Mountains. Right-lateral strike-slip (RLSS) displacement of the Qamsar and the Jazeh River beds are marked by arrows. Paleo- and modern-travertine springs are marked by X (D: Dorrin; KK: Kaftārkhun; KS: Kuh-e Sāhel; S: Sāhel; SH: Shurābeh; and ZS: Zard-e Sāhel).

Mounds, respectively. Excavations at both mounds revealed cultural layers from ca. 6000 BC through the first millennium BC (Ghirshman, 1938, 1939, 1951, 1964; Mallowan, 1970; Shahmirzādi, 2006).

The specific geographical location of the Sialk Mounds at the edge of the desert and adjacent to the >220 km-long Kāshān active fault (Fig. 1), which has recorded historical earthquakes, makes it sensitive and subject to numerous geological and environmental crises, such as earthquakes and related strong ground deformations, climate changes, sand storms, and flooding with accelerating incision. These issues have had considerable influence on the environment, landform, river pattern, vegetation, land-use, agricultural activities, metallurgical industry, and human life at the Sialk Mounds since the Early Neolithic.

Due to a lack of paleo-seismologic trench studies across the Kāshān fault, archeological data may provide insight into long-term seismicity and expand our knowledge of the temporal and spatial distribution of earthquakes. Numerous large-magnitude earthquakes have devastated ancient buildings and sites constructed adjacent to active faults. In addition earthquakes have affected ancient civilizations, controlled settlement patterns, and had long-term social and cultural impacts in Irān (Berberian, 1994, 2005; Berberian and Yeats, 2001).

The main purpose of this work is to bridge the gap between archeology, earthquake geology, and environmental science by examining the existing archeological data of the Sialk Mounds, which exhibit several millennia of cultural layers and hiatuses. In order to execute this difficult task we reviewed archeological data from the 1930s and 2000s, including a few rare, overlooked invaluable old photographs. In reviewing this data, we focus on the cultural gaps, strong ground motion indicators, paleo-architecture innovations, as well as paleo-environmental conditions of each period. We hope the paper will improve our knowledge of ancient

crises and bring awareness to these closely intertwined issues amongst the regional archeologists, seismologists, geologists, and paleo-ecologists. The analyses will drastically improve our knowledge of the activity of the Kāshān fault, improve the assessment of the seismic hazard of the region, and help mitigate the seismic risk for the present population as well as preserving the cultural heritage of the area during future earthquakes. Unresolved issues are also highlighted in the hope that future research projects will resolve the ambiguities.[1]

2. Seismotectonic setting

Active tectonics have played an important role on the landforms of the Iranian Plateau situated between the Eurasian and Arabian plates (Berberian, 1983; Berberian and King, 1981; Berberian et al., 1982), converging at about 25 mm/yr in a NNE–SSW direction (Sella et al., 2002). This compression has given rise to the present physiography and active morphotectonics of the area, which is comprised of high mountains, important mountain foot fertile lands with water supplies along mountain-bordering active faults, and pathways through them for migration and settlement of people through millennia.

Despite the absence of GPS-detected deformation in Central Irān over two-year (Vernant et al., 2004) and six-year (Masson et al., 2007) time period, recorded historical seismic data since 1755 (Berberian, 1994) and clear morphological evidence indicate that the Kāshān fault is a seismogenic fault (Fig. 1).

The Kāshān fault strikes NW-SE and is >220 km-long. It is mainly located to the eastern edge of the Karkas Mountains and the western edge of the Central Iranian Great Desert of Dasht-e-Kavir, adjacent to the Sialk Mounds (Fig. 1). To the north end of the fault a series of splay thrust faults are developed. To the south the fault dies out at the northern edge of the Gāvkhuni Playa, east of the city of Esfahān. Numerous paleo- and active travertine deposits are developed along the Kāshān fault line (e.g. Haidari, 2003; also see Section 4.1 below).

3. Archeological context

Prior to discovery of the Early Neolithic archeological site of '*Shurābeh Mound*' (Shahmirzādi, 2006) on the piedmont of the Karkas Mountains ('SH' in Fig. 1), it was believed (Ghirshman, 1938, 1939) that the first inhabitants of Sialk settled on the 'North Mound' around 6000 BC, while the last group of possible immigrants entered Sialk around 1200 BC, and buried their dead in 'Cemetery A' (Table 1). Ghirshman (1938) distinguished six distinct cultural periods at the Sialk Mounds. Accordingly, the cultural deposits of the first two periods, Sialk I and II, could be seen at the North Mound, and the cultural remains of the other four periods, Sialk III, IV, V and VI, could be seen at the South Mound. From our preliminary analysis of limited finds it seems that initially, during the Paleolithic and the Early Neolithic period, settlement to the west of the Great Desert was limited, and primarily clustered around the perennial springs, including paleo-travertine springs, formed along the Kāshān active fault. This environment provided rich natural fauna and flora resources and secure water supply, sheltered by the Karkas lofty Mountain to the west. During the Neolithic period people migrated to the open plain (Sialk North Mound) with water supplying larger cultivated lands from the Fin spring (Sialk I). Trend of growth continued to ca. 4300 BC (Silak II) when after a gap and a site shift, people occupied a new and larger site of the Sialk South Mound (Sialk III). Large-scale copper smelting and casting with silver extraction were the main industry of the new site. The Sialk North site was abandoned ca. 3400 and ca. 3100 BC. Since the archeological aspects of the site have been introduced in numerous papers and books cited in this study, we only present a summary of the important cultural characteristics of major periods (Table 1).

4. Archeoseismicity at the Sialk Mounds, Kāshān

Archeoseismology is a multidisciplinary study of strong ground motions created by ancient earthquakes through indicators left in the archeological record of ancient sites (Ambraseys, 2006; Marco, 2008). Valuable data about ancient earthquakes can be obtained by combining archeological, geological, and environmental data. In this section, we try to disentangle seismic versus environmental factors that we believe explain the cultural changes in the Sialk Mounds and the nearby archeological sites.

4.1. Drying up of the paleo-travertine springs at Zard-e Sāhel and Kaftārkhun [ca. Post-10,000 BC?]

Fossil and active travertine deposits have been mapped along the Kāshān fault (GSI, 1991, 1992, 1993, 1996; Haidari, 2003). The fossil travertine deposits at Zard-e Sāhel and Kaftārkhun, located in the area southwest of Kāshān (Fig. 1), are more compacted with fewer voids than the younger deposits, and their source springs are not extant. The Zard-e Sāhel fossil travertine as well as the Shurābeh and Khozāq travertine deposits, are located along the northern segment of the Kāshān seismic fault, west of Kāshān. On the other hand the Kaftārkhun and Dorrin travertine deposits are formed along the central segment of the Kāshān fault, in the area southwest of Kāshān (Fig. 1). Toward the southeast, an elongated palo-travertine with a length of about 9 km is deposited along the Kāshān fault in the area south of Abyāz (outside the study area; see GSI, 1991). It is clear that the travertine activity has been linked to the activity of the Kāshān fault. Ending the paleo-travertine spring activities could be associated with paleo-earthquake(s) generated by reactivation of the Kāshān fault.

Discovery of the Upper Late Paleolithic artifacts on top of the Zard-e Sāhel, Kuh-e-Sāhel, Sefidāb, and Fin-e Kuchek fossil travertine (Fig. 1) together with fragments of human skulls and bones sprayed with red-ochre (possibly part of the interment originally) on top of the Zard-e Sāhel travertine indicate that the paleo-travertine springs were occupied by people in the Upper Late Paleolithic (Biglari, 2003). The settlers with agro-pastoral activity were probably living during the 12,800–11,600 BP Younger Dryas arid climate in the vicinity of the travertine springs. Presumably, the Zard-e Sāhel travertine paleo-spring dried up sometime after this period, possibly because of an earthquake along the Kāshān fault. Presence of nearby active travertine springs immediately north of Zard-e Sāhel, as well as at Sefidāb may indicate that after the drying up of the Zard-e Sāhel spring, the new spring was formed at Sefidāb to its SSW (Fig. 1). U/Th dating of the numerous fossil travertine deposits along the Kāshān fault and paleoseismic trench studies will help resolve this issue, which is presented here only as a working hypothesis.

4.2. Abandonment of the Shurābeh Mound; possible migration to the Sialk North Mound [ca. 6000 BC]

The Early Neolithic, pre-Sialk I, Shurābeh archeological mound (Shahmirzādi, 2003, 2006) is located at an elevation of about +1100 m in the vicinity of the Kāshān fault and is sheltered at

[1] Note that in this report, Persian geographical names and other Persian words are written as they are correctly pronounced and written originally, with direct and simplified transliteration from Persian into English. Diacritical marks and special characters are used to differentiate vowel "A" [short; e.g. ant] from "Ā" [long; e.g. Armenian], and Arabic "ain" (used also in Persian) as "'A" [e.g. 'Abbās]. Elevations are above the mean sea level. Coordinates of the discussed sites are given in the Tables.

Table 1
Correlation chart of the Sialk and the Shurābeh archeological sites, Kāshān (based on Ghirshman, 1938, 1939, 1951; Shahmirzādi, 2006). For the location of the sites see Fig. 1. Major paleo-environmental crises are indicated in bold.

Date/Period	Shurābeh, Sefidāb, & Fin-e Kuchek Mounds	Sialk North Mound 33°58′26″N, 51°24′27″E; +952.02 m	Sialk South Mound 33°58′07″N, 51°24′15″ E; +967.94 m	Major cultural event	Architecture
637–652	Invasion of the Moslem Arabs: The Sāssānian city of Kāshān was destroyed in 644–5 AD				
~AD 224–642	Shurābeh, Niāsar, Vigol	–	–		Sāssānid
~250 BC–AD 224	Khozāq	–	–		Pārthian
330 BC	Invasion of Alexander III of Macedonia				
~550–300 BC	Khozāq		–		Āchāemenid
ca. 800–550 BC		–	Sialk VI (Necropolis B)		Houses on terrace foundation. Walls w/alternative courses of crude bricks & dry stones. Fortified town.
ca. 1200–800 BC		–	Sialk V (Necropolis A)		Fortified mansion on stone foundations w/alternative courses of crude bricks & dry stones.
<Hiatus>		**<Hiatus>**		**Abandonment**.	–
ca. 3400–3100 BC		–	Sialk IV	Inscribed tablets with numerical signs & letters.	Domed buildings.
<Hiatus>		**<Hiatus>**		**Abandonment**	–
ca. 3750–3400 BC		–	Sialk III$_{6-7b}$	Copper smelting and casting.	Walls became thicker & pebbles used in the foundations of Sialk III$_7$. Possible vault structures.
ca. 3900–3750 BC		–	Sialk III$_{4-5}$	Copper smelting and casting. Silver extraction.	Pebbles used in the foundations of Sialk III$_4$.
ca. (4300?) 4100–3900 BC		–	Sialk III$_{1-3}$	Hammered copper objects. Wheel-turned decorated kiln pottery. Stamp seals.	Spacious buildings w/ rectangular molded mud-bricks. Buttressed Walls. Relieved walls w/series of projecting panels.
<Hiatus>		**Sialk N. Mound Destruction**	**Construction @ S. Mound**	**Migration to Sialk S. Mound**.	–
ca. 5000–4300 BC		Sialk II$_{1-3}$	–	Improved kiln pottery technique. Annealing native copper. Cornelian & turquoise.	Plano-convex thumb-impressed hand-molded mud-bricks.
ca. 5600–5000 BC		Sialk I$_{4-5}$	–	Use of red-ochre & cold hammering native copper.	Plano-convex thumb-impressed hand-molded mud-bricks.
ca. 6000–5600 BC		Sialk I$_{1-3}$	–	Simple hand-made pottery.	Pisé & hand-made mud-bricks.
<Hiatus>		**Desertion of Shurābeh** (**?**)	–	**Migration to Sialk North Mound**.	–
Early Neolithic ca. 6200–6000 BC?	Shurābeh Mound [33°56′26″N-51°21′43″E; +1066]				Pisé hamlets (Shahmirzādi, 2003, 2006).
Upper Late Paleolithic	Sefidāb [33°55′′E–51°23′′E; +1030 m],				Stone tools (Biglari, 2003; Haidari, 2003).
Upper Late Paleolithic	Fin-e Kuchek [33°56′E–51°22′′E; +1040 m]				Stone tools (Biglari, 2003).
Lower Paleolithic [Acheulian; ca. 1.8 Ma–100,000 BP]	Tang-e Khozāq/Geleh [34°01′N-51°17′E; +1100 m]				Stone tool workshop (Biglari, 2003; Biglari and Shidrang, 2006).

the foot of the Kāshān fault scarp (Fig. 1; Table 1). With the except of the pre-Sialk I pottery, no other archeological material has been documented from the mound, which was later scraped by bulldozer for construction of a house! The lack of archeological data may indicate abandonment of the site sometime around 6200–5000 BC (Shahmirzādi, 2003, 2006). This time interval approximately corresponds to the 8.2 ka climatic event which was characterized by a prolonged drought/cool period well recorded almost all over the Northern Hemisphere (Rohling and Pälike, 2005; Ebbesen et al., 2008; Fleitmann et al., 2007). It has been shown that the 8.2 ka event correlates with major cultural changes in several archeological sites, e.g. in the Near East and Europe (Staubwasser and Weiss, 2006; Gronenborn, 2009; Akkermanns et al., 2010). As a working hypothesis, it is probable that during this dry/cold period the people might have left the high elevation Shurābeh site and settled in the lower plains of the Kāshān playa possibly at the Sialk North Mound.

4.3. *Collapsed walls exposed to the elements and abandonment of Sialk I settlement [ca. 5000 BC]*

Remnants of four collapsed pisé walls of ca. 5000 BC Sialk I period, were discovered at the Sialk North Mound (Jahāni, 2006). A layer of eolian sand deposit was discovered at an elevation higher than the four cases of the collapsed walls. The cause of the collapse of the walls is not known. However, the presence of eolian sand

deposits indicates that after the collapse of the structures, the area was abandoned and subjected to sand storms blown from the desert.

After the collapsed walls of Sialk I and the hiatus on the northern tip of the mound (Table 1) the new Sialk II settlement was relocated to the southern slopes of the same mound (Ghirshman, 1938). No evidence of invasion, war, violent upheaval, or climatologic/ecological deterioration has yet been recorded at the site (Ghirshman, 1938; Jahāni, 2006). It should be noted that during the 5000–4300 BC Sialk II period on the southern slopes of the mound, Neolithic 'thumb-impressed bricks' with four depressions on rounded and uniform size hand-made mud-bricks (Ghirshman, 1938) were utilized for better lodgment and interlocking with mortar and stability of the structure (Table 2). The use of the finger-impressed mud-bricks at Sialk II was introduced after the collapse and abandonment of the Sialk I structures at the northern quarter of the North Mound. An earthquake occurrence can be speculated, but not proven, with the existing limited excavated data. Additional careful excavation will help our understanding of the cause of destruction and settlement relocation.

4.4. Abandonment of the Sialk II North Mound; settlement at the Sialk III South Mound [ca. 4300 BC]

At the end of the Sialk II period around 4300 BC, the older North Mound was abandoned. After a short hiatus of possibly 200 years or more, people migrated to the new location (the South Mound), where for the first time they built rectangular houses with 'buttressed' walls (Tables 1 and 2). Due to a lack of radiometric dating, the exact duration of the hiatus is unknown at this stage. Furthermore, the cause of destruction, abandonment, migration and the shift from the North Mound to the South Mound remains unclear. The shift is not caused by over-population and/or over-stress on local ecological habitats and no evidence of violent conflict has been found at the site (Ghirshman, 1938, 1939, 1951, 1964; Mallowan, 1970; Shahmirzādi, 2004, 2006).

It is clear that the beginning of the Sialk III at the new southern site marks the disappearance of certain features (Tables 1 and 2). Some general elements do continue from the Sialk II period, but a variety of new features appear during this considerably more

Table 2
Correlation chart of the Sialk cultural periods, archeoseismicity data, and architectural innovations for structural resilience [Background shadings: Dark gray: environmental crises especially archeoseismic events; Light gray: hiatus]. Major paleo-environmental crises are indicated in bold.

Approx. date	Sialk periods	North Mound	South Mound	Architectural innovations	Abnormal annotations
300 BC	Invasion of Alexander III of Macedonia				
550–300 BC	Āchāemenid		–	–	–
ca. 800–550 BC	VI (Cemetery B)	–	**7th Century BC event (?)**	**Firm foundation w/interlacing brick work & thick walls.**	**Collapse of exterior wall 402, room 404 (~7th century BC); Post-VI fractures cutting Trench 3.**
ca. 1200–800 BC	V (Cemetery A)	–	Migration of Indo-European tribes to Sialk.	Fortified mansion on stone foundations w/alternative courses of crude bricks & dry stones.	–
<**Hiatus**> **ca. 3100–1200 BC**	<**Hiatus**>				
Ca. 3400–3100 BC	IV	–	**Post- 3100 BC Event (?)**	Well-developed sophisticated large-scale construction.	**Post-3100 BC fracture cutting the South Sialk IV_2 buildings (3200 BC).**
<**Hiatus**> **ca. 3400 BC**	<**Hiatus**>				
ca. 3750–3400 BC	III_{6-7b}	–		**Walls became thicker & pebbles used in the foundations of Sialk III_7.**	–
ca. 3800 BC			**Sialk III_5 earthquake + fire**		**Collapsed roof killing a girl & two infants, w/ numerous fractures cutting the South Sialk III_5 (3800 BC).**
ca. 3900–3750 BC	III_{4-5}	–		Pebbles used in the foundations of Sialk III_4.	–
ca. 4100–3900 BC	III_{1-3}	–		**Rectangular mold mud-bricks. Buttressed walls; relieved wallsw/series of projecting panels.**	–
<**Hiatus**> **ca. 4300–4100 BC**		**N. Mound destruction**	**Migration to S. Mound**	–	
ca. 5000–4300 BC	II_{1-3}	–	–	**Thumb-impressed, plano-convex mud-bricks for additional lodgment.**	–
<Hiatus> ca. 5000 BC?		**Northern & central quarters abandoned; migration to the Southern slopes.**	–	–	**Collapsed walls; abandonment of Sialk I at northern quarter of North Mound & migration to the southern slopes; aeolian sand.**
ca. 5600–5000 BC	I_{4-5}	I_{4-5}	–	–	–
ca. 6000–5600 BC	I_{1-3}	I_{1-3}	–	–	–
<**Hiatus**> **Pre-6000 BC**	**Desertion of Shurābeh**	**Migration to Sialk North Mound**	–	–	
Early Neolithic ca. 6200–6000 BC?	Pre-I Shurābeh Mound	–	–	–	–
ca. 10,000 BC?	–	–	–	–	**Cease of the Zard-e Sāhel Paleo-travertine spring**

prosperous and developed period, possibly by a new influx of people (Ghirshman, 1938). We know that the shift is accompanied by: (i) construction of rectangular houses with 'external buttressed' walls; (ii) the first modern, rectangular, flat sided mold-bricks at the beginning of Sialk III; (iii) the introduction of high-quality wheel-made pottery; (iv) extensive copper–silver smelting industry; (v) long distance trades with the Persian Gulf shore; and (vi) stamp seal employment (Ghirshman, 1938, 1951, 1964) (Table 2). The buttresses and rectangular structures could be considered innovative attempts to minimize ground motion damages.

Based on (i) the positions of the skeletons, and (ii) the volume of the collapsed debris, the 'shift' of the Sialk settlement from the North Mound to the South Mound after a hiatus was considered by Ghirshman (1938) to be the result of "*some sort of disaster, possibly an earthquake*". There is a vertical fracture mapped from the upper right corner step of Trench A [in Ghirshman Operation No. 1] in the North Mound, extending from the ground surface to the depth of 1 m below the grades (Shahmirzādi, 2004, 2006). Unfortunately, the excavation ceased at this level and the downward propagation of this vertical fracture and its effects on the cultural layers of Sialk I and the sterile soil is unknown at this stage. An earthquake can realistically explain the abrupt end of the Sialk II period of life at the North Mound; however, we cannot unequivocally assign the site shift to a major earthquake without further on-site investigation.

The timing of the hiatus/shift (Table 3) seems to be 'contemporaneous' with one of the major climatic events that affected the whole SW Asia at around 6.3 ka (Fleitmann et al., 2007; Djamali et al., 2010). This time is characterized by the regional southward shift of the Inter-Tropical Convergence Zone (ITCZ) which marks the northern limit of the influence of the Indian Summer Monsoon (Fleitmann et al., 2003). This climatic shift has had dramatic effects on the climate, hydrology and vegetation of the area. Extensive areas in the Arabian Peninsula, SE Middle East, and NW Indian subcontinent, which received the monsoon summer rain, became deprived of the summer precipitation and underwent a large-scale drought (Singh et al., 1990; Fleitmann et al., 2003, 2007; Lézine et al., 2007). In contrast, in the central and northern Zāgros Mountains and eastern Anatolia, the 6.3 ka event had a positive effect on the effective moisture and caused the re-expansion of the Zāgros-Anti-Taurus oak woodlands (Djamali et al., 2010). Unfortunately, the paleo-environmental records are almost completely missing from the Central Iranian Plateau, where the Sialk is located, but judging from the available records in the adjacent regions it seems that the past interactions of climatic systems over this vast area have been extremely complicated. Future excavation and paleo-environmental studies are needed to resolve the effect of the ITCZ as well as the possibility of an earthquake occurrence in the area.

4.5. The Sialk III$_5$ period earthquake [ca. 3800 BC]

We focus here on two independent excavation results conducted in the 1930s and the 2000s. The distance between the two excavations is about 150 m (Fig. 2).

4.5.1. G. T. 3 (South Mound, 1938)

During the first excavation at Sialk South Mound in the 1930s (Ghirshman Trench 3; Fig. 2), at the corner Room 5 of Sialk III$_5$, a skeleton of a woman lying near a window, which opens to a narrow corridor, protecting two small children in her arms, was found being crushed by the fall of the roof and/or walls (Figs. 3 and 4; Table 1; Pls. XXV.2 & XXIV.4 in Ghirshman, 1938; Mallowan,

Table 3
Correlation Chart for the Sialk, Arismān, and Hesār copper–Silver processing centers at the periphery of the central Iranian Great Desert (Dasht-e-Kavir) [Background shadings: Dark Gray: Extensive use of Wood as fuel for large-scale copper smelting Process; Medium Gray: Abrupt arid/cooling or warm/dry climate Change; Light Gray: Hiatus]. Major paleo-environmental crises are indicated in bold.

Sialk [~+950 m] (Ghirshman, 1938; Shahmirzādi, 2006)	Major events/crises (BC)	Arismān (Helwing, 2006) [33°39′N-51°58′E; +1098 m]	Hesār (Dyson, 1987; Dyson and Howard, 1989) [36°09′N-54°23′E; +1195 m]	Major Climate change episodes (Kay and Johnson, 1981; Weiss, 2000; Stevens et al., 2006; Fleitmann et al., 2007)
800–550 BC: Sialk VI (Cemetery B).	New residents			
1200–800 BC: Sialk V (Cemetery A).	New residents			1200–900 BC Warm/Dry Climate.
<**Hiatus**> **3100–1200 BC**	Collapse of Hesār IIIC (1700 BC)		2000–1700 BC: IIIC	1700–1200 BC
			2900–2000 BC: IIIB	**ca. 4.2 ka: Drought/Cooling Event** (**~2200–1700 BC**)
	Collapse of Arismān (2600 BC)			3000–2200 BC
		2900–2600 BC: Slag Heap E Area C Phase 3 (graves).	2900–2600 BC: IIIA	
		3100–2900 BC: Slag Heap A Area C, Erosion phase & secondary workshops.	3100–2900 BC: IIC	
	Collapse of Sialk IV$_2$ (3100 BC)			**ca. 5.2 ka: Draught/Cooling Event** (**~3600–3000 BC**)
3400–3100 BC: Sialk IV$_{1-2}$ (North).		3400–3100 BC: Area C Phase 6–4 Slag Heap D.	3400–3100 BC: IIB	
<**Hiatus**> **ca. 3400 BC**	Collapse of Sialk III$_7$ (3400 BC)	3600–3400 BC: Area B Pottery Kilns.	3600–3400 BC: IIA	
3900–3400 B.C.: Sialk III$_{4-7b}$ (North).	**3800 BC Earthquake**	3900–3600 BC: Area B occupation.	3900–3600 BC: IC	6000–3600 BC
4100–3900 B.C.: Sialk III$_{1-3}$ (North).			4500–3900 BC: IA/B	
<**Hiatus**> **4300–4100 BC**	Collapse of Sialk North. Migration to Sialk South (4300 BC).			
5000–4300 BC: Sialk II (South).	Shift from northern tip to southern slopes.			
6000–5000 BC: Sialk I (South).	5000 BC: Collapsed walls & Erosion.			
<**Hiatus**> **ca. 6000 BC**	Migration to Sialk North.			
6200–6000 BC Shurābeh ?	Collapse of Shurābeh (6000 BC) ?			**ca. 8.2 ka: Draught/Cooling Event** (**~6500–6000 BC**).

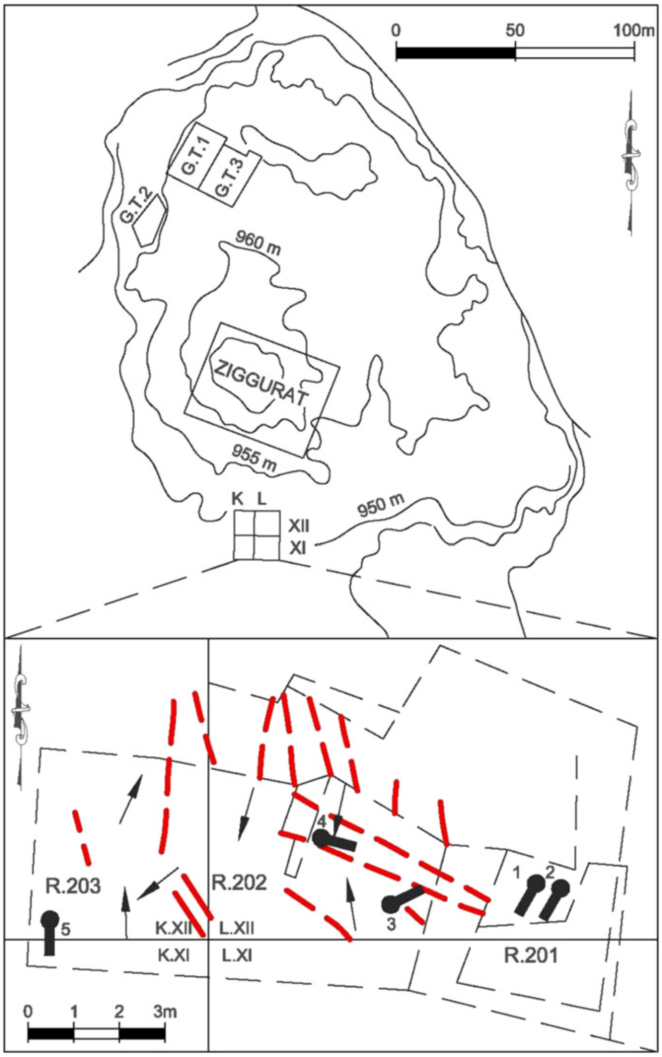

Fig. 2. Effects of the Sialk III_5 period (~3800 BC) earthquake observed in Rooms 201, 202, and 203, Trenches K.XI & XII and L.XI & XII of the Sialk South Mound (modified after Nokandeh, 2003). Directions of the toppled large jars are shown by arrows. Bodies smashed by the fall of ceiling and wall debris are shown by black tadpoles (Nos. 1 through 5). Location of the ground fractures developed on the floors and/or the wall is transferred from photographs and is, therefore, approximate.

Fig. 3. Sialk South III_5 period [ca. 3800 BC] construction (Pl. XXIV.4 in Ghirshman, 1938). The skeletal remains of a mother lying near a window opening to a narrow corridor, protecting her two small children in her arms were found being crushed by the fall of the roof of the building (corner Room 5 of Sialk III_5; mid-bottom right corner of the photograph). See Fig. 4 for the close up view. Dimension of Room 5 is approximately 3 × 3 m. Also note a nearly vertical fracture cutting the wall next to the person standing at the top left corner (Room 9). North is approximately to the right of the photograph and woman's feet are stretched toward WNW.

1970). Ghirshman (1938) also referred to several other crushed skeletons at the same horizon by the fall of debris (Fig. 5; Pl. XXV.3, Ghirshman, 1938) and mentioned that although the walls were taller, the amount of fallen and disturbed debris in the rooms suggests that the roofs were dome-shaped, built by mud-bricks. On Pl. XXIV.4 (Ghirshman, 1938), which shows the Sialk III_5 construction with the skeleton of the mother and the two kids, a fracture (Fig. 3) can be seen cutting the wall on the left-hand side of the unexcavated wall to the SW of Room 9. Upon comparing this with Ghirshman's Pl. LX Période III_5, the fracture seems to be cutting the southern wall of the trench, SW of Room 9. The same fracture can also be traced on his Pl. XXIV.3 (SIalk III_4 constructions), in the area south or southwest of Room 7 of Sialk III_4, on the same unexcavated wall to the SW of Rooms 3 and 7 of III_4 (see Pl. LX Période III_4 in Ghirshman, 1938).

4.5.2. Rooms 201–204 (South Mound, 2003)

Recent excavation of a residential area dating to the end of Sialk III_5 period [ca. 3800 BC], testified to an abrupt and violent destruction of the buildings by fallen walls and ceilings over crushed skeletons and large painted storage jars in three excavated rooms (Foruzānfar, 2003, 2004; Nokandeh, 2003, 2010; Shahmirzādi, 2006). The excavation area (Rooms 201, 202, & 203 in grids L.XI, L.XII, & K.XII; Fig. 2) is located about 150 m to the south of Ghirshman's excavated Room 5 (Trench 3) of Sialk III_5 with crushed skeletons.

4.5.3. Room 201, L.XII (South Mound)

Two skeletons were discovered in this room (Nokandeh, 2003). The two bodies were laid down side by side and presumably were killed while sleeping (Fig. 2).

4.5.4. Room 202, L.XII (South Mound)

In the middle Room 202 (L.XII), the skeletal remains of an approximately ten-year old girl (Skeleton No. 3) and a 30–35 year old man (Skeleton No. 4) who were killed by the collapse of the building were discovered (Fig. 2). The head of the male body is close to the western wall, whereas the young girl was found smashed by fallen debris close to the eastern wall. There was broken pottery, together with debris, over skeleton No. 3 (young girl) and the skeleton was surrounded by broken pieces of pottery (Fig. 6). The femur diaphysis of the girl's left leg was broken and oriented in two different directions, indicating that it was broken by a falling heavy

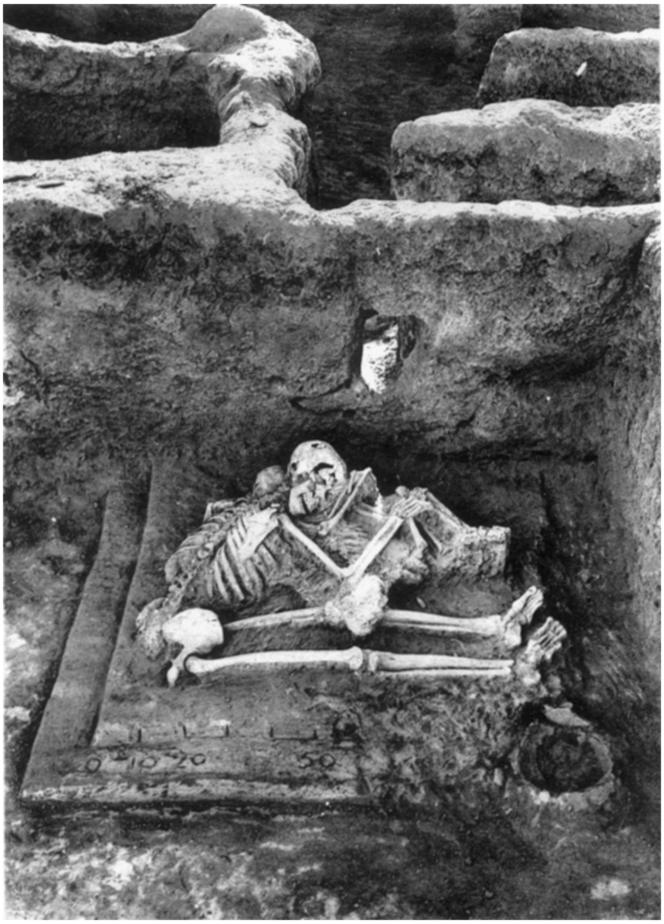

Fig. 4. Sialk South III_5 period [ca. 3800 BC] construction (Pl. XXV.2 in Ghirshman, 1938). Close up view of the corner Room 5 of Sialk III_5 (for location see Fig. 3) showing the skeletal remains of a mother protecting her two small children in her arms killed by the fall of the roof of the building. The upper level platform immediately below the skeletons is approximately 90 cm (looking approximately to the south).

Fig. 5. A badly crushed and smashed skeleton of a grown up male person by fallen heavy debris of Sialk South III_5 period, ca. 3800 BC (Pl. XXV-3 in Ghirshman, 1938). Apparently, the man was in squatting position and the collapsing debris grounded him on his left side. The left foot is dismembered; the right foot is folded; and the rest of the smashed bones are near the folded foot.

object (Fig. 6). Her backbone was shifted to the left side of her chest. Her right hand was broken from the shoulder blade and was displaced underneath her upper left ribs. The girl was facing down with her arms beneath her body, and her broken skull (with broken condylus occipitalis) was indented into the floor (Fig. 6). Skeleton No. 4 (male) shows broken skull, neck, ribs, right hand, and femur. The right hand of the male body was in front of his face (Figs. 7 and 8).

No evidence of burial was observed and all the individuals were found on the same approximate level in different rooms, and the skeletons were crushed by the collapse of the building. Furthermore, a large painted empty storage jar, located to the south of the body, was crushed and the broken pieces of pottery were scattered all around and over the body and mixed with the fallen debris. Broken and unbroken mud-bricks ($34 \times 22 \times 10$ cm) were found on top of the skeleton (Figs. 7 and 8). An '*overturned*' and broken jar was found in the northeastern part of Room 202. The eastern and western walls of Room 203 are '*tilted*' inward (Foruzānfar, 2003, 2004; Nokandeh, 2003; Dehqān-nezhād, 2003). Several '*fractures*' cut the eastern and the northern walls as well as the floor of Room 202 (Figs. 9 and 10).

4.5.5. Room 203, K.XII, K.XI (South Mound)

In the western storage Room 203 (grid K.XII; Fig. 2) were the remains of approximately ten medium- to large-sized empty storage jars and vats, which had been crushed into fragments by the collapse of the debris. The largest painted storage jar was 1.33 m long with a 78 cm diameter at the mouth. The empty large storage jars may indicate that the earthquake occurred during the pre-harvest season, or that the jars included perishable materials and/or liquids. One of the large storage jars located in the northeast corner of the room partially remained in its original nearly upright position (possibly supported by the two walls), while it's upper part was shattered by the falling debris and was flung toward the center of the room. An 'overturned' and broken jar was found in the eastern part of Room 203. In addition, a 25–30 year old crushed female skeleton (No. 5; Fig. 2) was discovered in this room (Foruzānfar, 2003, 2004). Radiocarbon dating of a sample collected from the same level in the nearby trench, analyzed by the University of Cambridge, U.K., yielded 3750–3950 BC for this cultural layer (Nokandeh, 2010). The long painted storage jars toppled toward the N, NNE, NNW, or SSW (Fig. 2). Furthermore, numerous parallel, nearly E–W and N–S fractures in the same horizon were developed cutting the eastern and the northern walls as well as the floors of the rooms (Figs. 9 and 10).

The crushed skeletons of the Sialk III_5 period inhabitants at two locations 150 m apart from each other (Fig. 2) were not buried in graves underneath the floor, but were killed under the debris of fallen buildings. The collapse came suddenly, without warning, and caught them possibly in their sleep or a lying down position. Bearing in mind that the site is located about 6 km to the east of the Kāshān active fault (Fig. 1), which is known for historical seismicity, the possibility of destructive earthquakes occurring at the site is high. We assign the Sialk III_5 event to an earthquake around 3800 ± 200 BC (Tables 1 and 2). The evidence, while indicating the occurrence of a large-magnitude earthquake (>VIII) at Sialk, is not by itself sufficient to permit a definite interpretation of the earthquake damage extent and its highest epicentral intensity. The lack of data from areas other than Sialk makes it difficult to determine the

Fig. 6. The smashed skeleton of approximately 10-year old girl still partially covered by the fallen debris in Room 202 (No. 3 in Fig. 2), Trench L.XII of Silak South III_5 period (ca. 3800 BC). The scale length is 50 cm. The skull is directed to the SW. Looking to the WSW. Photographed in 2003 during excavation.

seismic parameters of the earthquake. The effect of this earthquake at the 3900–3600 BC Arismān 'Area B Occupation' (Helwing, 2006) archeological site (if any) is unknown. Paleo-seismological trenching across the Kāshān fault as well as careful excavation of the adjacent mounds are needed to determine the seismic parameters of this and other seismic events.

As mentioned above, the large painted storage jars in Rooms 202 and 203 toppled toward the general N–S or NE–SW direction (Fig. 2). Bearing in mind that the Kāshān fault is a NNW–SSE right-lateral strike-slip fault, and the Sialk Mounds are located on the eastern block of the fault (Fig. 1), a sudden right-lateral motion along the fault line during the earthquake could topple the free-standing objects toward the general N–S direction (Figs. 1 and 2). The two '*overturned*' and crushed jars found in Rooms 202 and 203, underneath debris of the collapsed walls/ceilings, could be interesting evidence of 'strong ground acceleration' if they were

Fig. 7. The smashed skeleton of a male body and a fallen large broken jar next to the body by the fallen debris in Room 202 (No. 4 in Fig. 2), Trench L.XII, Sialk South III_5 period (ca. 3800 BC). Mud-bricks dimension: 34 × 22 × 10 cm. The skull (right) is directed to the WNW. Looking to the SW. Photographed on 1 February 2003 during excavation.

Fig. 8. A close up view of the smashed skeleton of a 30–35 years old man and a fallen large broken jar next to the body by the fallen debris in Room 202 (No. 4 in Fig. 2), Trench L.XII, Sialk South III_5 period (ca. 3800 BC). Note the fallen brick on the skull. Mud-brick dimension: 34 × 22 × 10 cm. The skull is directed to the WNW. Looking to the NW. Photographed on 29 January 2003 during excavation.

originally laid down in an upright position. We know that objects are upthrown, 'overturned,' and displaced during strong ground motions created by large-magnitude earthquakes.

The foundations at the Sialk III_5 period buildings usually consisted of ruble masonry. The buildings were box-shaped with walls at right angles, which were tied together at the corners, and the floors were made of compacted soils. Although the ceilings were collapsed by the earthquake, some seem to be constructed with reeds (Nokandeh, 2003). Dome-shaped roofs with mud-bricks were also reported by Ghirshman (1938) about 150 m to the north. The intent of these architectural measures was to carry the weight and increase the stability of the structures and to knit the walls closely together, possibly in an effort to counter the possible damage from earthquake destruction and/or uneven settlement of

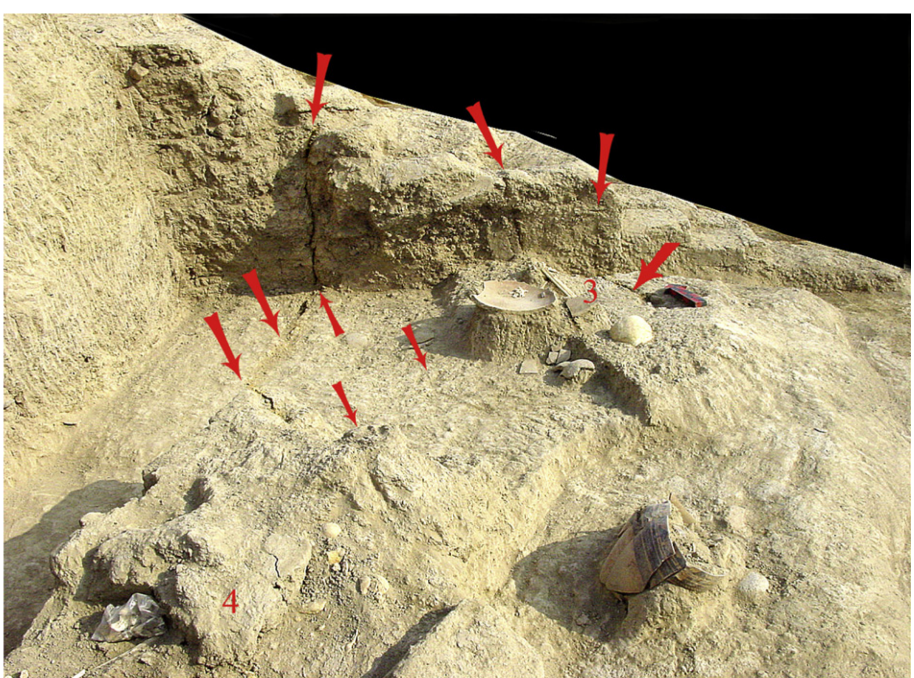

Fig. 9. A view of Room 202, Trench L.XII of Silak South III_5 period (ca. 3800 BC) with the debris covered skeletons of the male (No. 4; bottom left) and the girl (No. 3, top center). The distance between skeletons 3 and 4 is about 2.5 m. Note the fractures cutting the eastern wall as well as the floor. The single foreground mud-brick dimension: 34 × 22 × 10 cm. Looking to the east. Photographed in 2003.

Fig. 10. View of nearly N–S fractures cutting the northern walls and floor of Room 202 (right; with two excavated smashed skeletons covered by plastic boxes), and Room 203 (left), Trench L.XII of Silak South III_5 period (ca. 3800 BC). The dimension of Room 202 (right) is 2.5 (N–S) by 4 m (E–W). See Fig. 2 for the location. Looking to the north. Photographed on 27 May 2009.

the structures. After the Sialk III_5 earthquake destruction, the newly built walls were constructed thicker, pebbles were used in the foundation, and stone layers were added to the walls of the structures of the 3750–3400 BC Sialk III_{6-7} (Ghirshman, 1938). These changes were possibly introduced after the Sialk III_5 (3800 BC) earthquake (Table 2).

4.6. Hiatus between Sialk III and IV [ca. 3400 BC?]

Based on observation of: (i) construction of the Sialk IV structures on the Sialk III ash layers containing skeletons, and (ii) the distinct difference between Sialk III and IV ceramics, with a hiatus in between, Ghirshman (1938) theorized the '*Proto-Elamite occupation at Sialk III_{7b}*' as a result of an invasion from Susā (Tables 1 and 2). He mentioned that the top of Sialk III_7, designated as 7b in his Pl. LIX of trench 3, is '*severely disturbed*' showing '*damages and losses caused by a violent event*'. Herrmann (1968) also mentioned that Sialk III_{7b} was invaded and destroyed by the Elamites. This idea was later questioned by Majidzādeh (1989). The exact cause of the Sialk III–IV gap and destruction is not yet clear. The short hiatus between Sialk III and Sialk IV, with unconstrained ages, seems to 'coincide' with a severe and prolonged regional drought in 3600–3000 BC (Table 3). This is suggested based on the paleo-ecological record of the Lake Mirābād ('Mirabad' in the paleoclimatic literature) in the western Zāgros (Stevens et al., 2006). However, caution should be taken to correlate these two events because of the low resolution of the Mirābād record.

4.7. Large fractures at Sialk IV South Mound [ca. 3200–3100 BC] and hiatus between Sialk IV and Sialk V [3100–1200 BC]

An invaluable but overlooked photograph published by Ghirshman (1938) shows a previously unnoticed long fracture cutting through all the excavated 'Sialk IV_2' period structures, ca. 3200–3100 BC, at the South Mound with a vertical drop on the right hand side of the photograph (Fig. 11 and Table 2; Pl. XXXII, No. 1 in Ghirshman, 1938). The age of this fracture is unknown and the fracture is not described by Ghirshman and the later investigators. Since the buildings are dated Sialk IV_2, 3200–3100 BC, it should be a post-Silak IV_2 feature. After the Sialk IV_2 period (~3100 BC; Tables 1 and 2) the site was completely deserted for approximately 1900 years [ca. 3100–1200 BC], the cause of which is unknown. The Iron Age invaders (Sialk V; ~1200 BC) settled on the ruins of the Sialk IV remains (Ghirshman, 1938).

Although the cause of the commencement of this hiatus is not clear, we know that the upper middle stages of the prolonged hiatus between Sialk IV and Sialk V, which lasted about 1900 years, was 'concurrent' with a prolonged aridification during ca. 2200–1700 BC (Weiss, 2000) (Table 3). It is plausible that this abrupt climate change prolonged the extent of this unusual protracted hiatus at Sialk. The so-called 4.2 ka event has been detected in numerous paleo-records especially over the Northern Hemisphere (Booth et al., 2005) and has been considered by some authors as the main cause of the decline of civilizations and sudden cultural changes in SW Asia (Weiss et al., 1993; Staubwasser and Weiss, 2006). Despite the climate conditions improving between ca. 1700 BC and 1200 BC, no cultural layer is recorded at the Sialk Mounds (Table 3). It is probable that the remains of such evidence were partially removed by the Iron Age partial leveling and construction. This long gap at Sialk deprives us of the local life, environmental, and seismological conditions.

4.8. Collapse of the Iron Age III exterior wall [ca. 7th century BC]

The 2.5 m-wide exterior mud-brick 'Wall 402' of Iron Age III [800–500 BC] layer 1, had collapsed sideways on the northward slope. The room was abandoned, leaving an assemblage of assorted vessels and finds exposed to weathering and erosion (Helwing, 2005). The fallen wall had inflicted severe damage to the underlying features and an erosion gully had cut deeply into the wall debris and the layers below. It was, then, hypothesized that the Iron Age III room, equivalent to Sialk VI/Necropolis B (Table 2), might

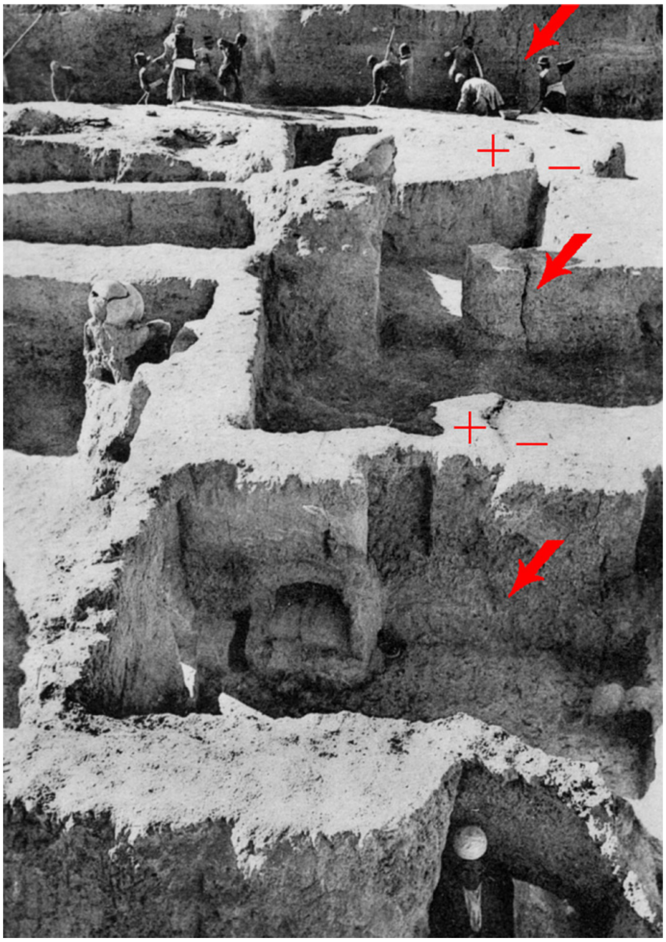

Fig. 11. Sialk South Mound IV_2 period [ca. 3100 BC] construction (Pl. XXXII-1 in Ghirshman, 1938). Note a post-IV_2 [ca. 3100 BC] long linear fracture cutting the structures along the right site of the photograph with vertical settlement of the right side block in this invaluable overlooked historic photograph. Arrows and + and − signs are added to the original invaluable photograph. The approximate strike of the fracture is estimated in a general NE–SW direction (exact geographic direction unknown). Looking possibly to the SW. The dimension of the uppermost right excavated room is 3 × 2 m.

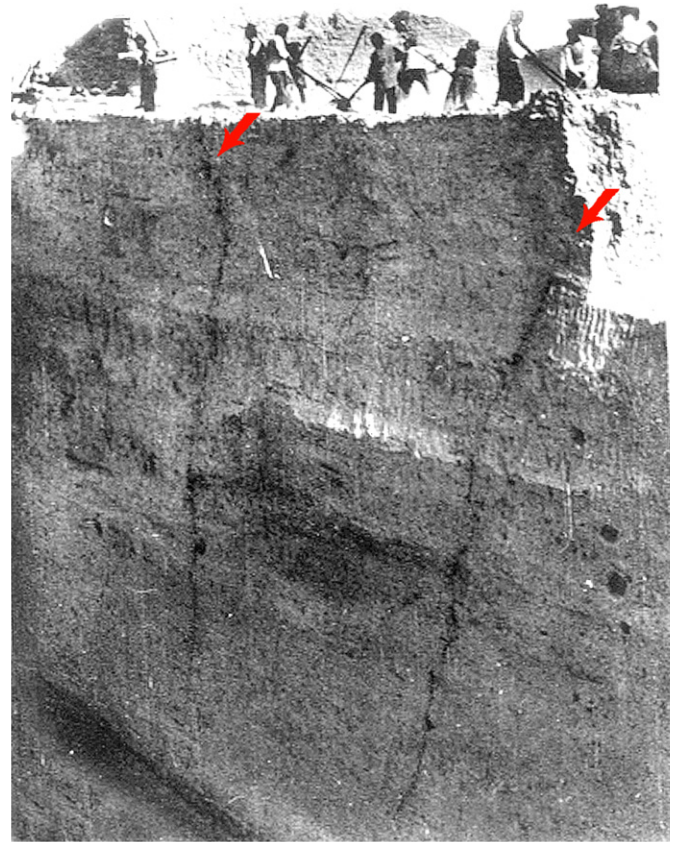

Fig. 12. Northeastern trench wall of the Sialk South (Ghirshman's Trench G.T.3, 1937; Pl. XXIV.1 in Ghirshman, 1938). For location see G.T.3 in Fig. 2. Note the two long nearly vertical ground fractures (possibly post-Sialk VI period; ca. 800–500 BC?) cutting the cultural layers of Sialk III, IV, V, and possibly VI (?). The fractures are possibly oriented in a general N–S direction. Arrows were added and the historic photograph is slightly enhanced for highlighting the two deep vertical ground fractures. The depth of the trench wall is 13.5 m.

have been destroyed by an earthquake (Helwing, 2005). No additional evidence of earthquake damage is reported from this horizon due to limited excavation. The Wall 402 of building 404 was located at the edge of the cliff-like slope and no further structure stood to the west of the wall to prevent its collapsing on ancient surfaces below the slope. A nearly vertical fracture is mapped between 402 West N and 402 West S walls (grid J30, location 6–7 in east profile A–B and frontal view of Wall 402 in Fig. 11 of Helwing, 2005). The nature of this fracture is unknown at this stage.

The archeological signature of the critical location of Wall 402 and the limited examples of collapsed structures is not as strong as the evidence of the ca. 3800 BC Sialk III_5 earthquake discussed earlier. The limited data give little technical justification to unequivocally support the conclusion that the destruction of wall 402 was due to an earthquake around the 7th century BC. However, in two communications with Barbara Helwing (Personal Communication; April 4 2008 and October 25 2010), she mentioned that "*Wall 402 was a solid wall standing on an almost even ground and was sheared off at the base*". Additional excavations along the Iron Age III layer may resolve this issue.

Careful review of another invaluable and overlooked old photograph (Ghirshman's 1938 Pl. XXIV.1) shows two long and near vertical fractures on the right side of the Trench 3 wall (possibly the northeastern trench wall) on the South Mound (Figs. 2 and 12). The depth of the trench is ~13.5 m bgs and it is not clear that the two fractures cut the sterile soil (about 12.6 m bgs) and the topmost, post-Sialk VI sediments at the surface. As with the previous old photograph (Fig. 11) Ghirshman and his followers did not notice the importance of the two fractures and we found no reference to them in the literature. The layers from the top to the bottom (Pl. LIX in Ghirshman, 1938), which are cut by these two fractures, belong to Sialk VI (at the top; near surface to 2.5 m bgs) to Sialk V (2.5–3.5 m bgs), Sialk IV (3.5–5.4 m bgs) and Sialk III (at the bottom; 5.4–12.6 m bgs). Since all the layers from Sialk III to Sialk VI are cut by the two deep fractures, the seismic event can be relatively dated at this stage as "Late Iron Age III" or "Post- Late Iron Age III." It is probable that the formation of the fractures and the collapse of the Iron Age III exterior wall are caused by a single event. Further research is needed.

5. Concluding remarks

By examining a complex set of archeological, architectural, metallurgical, paleoclimatic, geologic, and seismologic data from various sources, we tried to learn more about the possible devastating effects of earthquakes and environmental changes on the human civilizations in the Sialk/Kāshān area. Our review and analyses provided an important new body of evidence through a narrow window into the dynamics of the Sialk Mounds along the

Kāshān active fault, which can be used for discussion as well as further research activities. It delivered new insights into the time range of several crucial natural and anthropogenic events and crises preserved at the archeological sequence of the area. However, due to limited data our preliminary interpretations could be a simple approach to a much more difficult and complex task. Nonetheless, we tried not to push the available fragmented and limited data beyond a comfortable zone. It is hoped that the small step and synthesis taken in this article will serve as (i) a stimulus for further multidisciplinary research both at the site and in the country, and (ii) will broaden our understanding of the wide range of issues barely touched and addressed either by the original excavators or by us in this report. Unfortunately, numerous limitations prevented detailed analyses of the stratigraphic, environmental, social, economic, and political nature of the site. Most of the relevant primary sources are cited for re-examination and clarification of some problematic issues.

The oldest well-documented large-magnitude earthquake evidence devastating the Sialk region took place ca. 3800 BC along the northern segment of the Kāshān fault. The earthquake destroyed the buildings, fractured the ground, toppled the objects in a nearly N–S direction, and killed the people under debris. Other ancient earthquake episodes, such as ca. 10,000 BC, ca. 5000 BC, post-3200 BC, and ca. 7th century BC, are suspected and discussed in this study but cannot be proven with the present limited available data (Table 2). However, it seems that after each suspected paleo-earthquake new indigenous architectural elements were innovated for construction of more sustainable buildings. We believe that during the last 8000 years (Table 1), the Sialk area adjacent to the Kāshān active fault (Fig. 1) should have been destroyed by more earthquakes than the few analyzed in this paper.

Despite earthquake destruction reports of the city of Kāshān in 1755 and 1778 along the northern segment of the Kāshān fault (Fig. 1), no specific reference to an earlier medium- to large-magnitude earthquake is found in the Natanz area along the southern segment of the Kāshān fault (69 km southeast of Sialk/Kāshān). All evidence points to a relatively local quiescence of at least 687 years along the southern segment of the Kāshān fault. The earliest man-made free-standing structure in the city of Natanz, the 1325 AD, 37 m-high minaret of the shrine complex of Shaikh Nur al-Din 'Abd al-Samad (Wilber, 1955; Blair, 1983, 1986), is still standing adjacent to the Natanz Jāme' mosque and to the southeast of the Sāssānid (224–642 AD) fire temple in the vicinity of the Kāshān fault. The extant, free-standing structure for the last 687 years, together with the Ilkhānid (1218–1334 AD) Kucheh Mir mosque, and the Safavid (1491–1722 AD) caravanserai to its south, supports the view that during that period there would have been no locally destructive earthquake along the southern segment of the Kāshān fault. The city of Natanz, with a minimum 687 years of interseismic quiescent period, is at high risk of a large-magnitude earthquake in the future.

There seems to be a 'correlation' between the major climate change episodes confirmed in the Middle East and Western Asia and the decline in settlement activity in environmentally sensitive sites such as Sialk, Arismān, and Hesār fringing the Central Iranian Great Desert (Table 3). The considerable hiatuses at the Sialk Mounds were detected ca. 6000 BC, ca. 4300–4100 BC, ca. 3400 BC, and ca. 3100–1200 BC (Table 3). During the hiatus episodes, the inhabitants had to abandon the site and migrate to more favorable sites which are still unknown to us and which may have caused changes in their socio-economic structure. Based on the excavated sites, there is not enough evidence to judge whether the decline and hiatus is a site detectability issue or a real regional crisis. While Sialk was abandoned around 3100 BC, during the 3600–3000 BC drought/cooling event, other sites in different domains, such as Hesār in the north (Table 3; Dyson, 1987; Dyson and Howard, 1989), Tapeh Yahyā (Lamberg-Karlovsky, 1970; Lamberg-Karlovsky and Potts, 2001), and Shahr-e Sukhteh in the SE (Lamberg-Karlovsky and Tosi, 1973; Amiet and Tosi, 1978; Tosi, 1983), were flourishing. It would be interesting to compare the timing of cultural phases with climatic events in different geographic areas of the continental Middle East. This, before anything, necessitates producing new, high-resolution paleo-environmental data from this region in the future.

In order to improve our understanding of natural and man-made hazards which imposed crises at the Sialk Mounds, the city of Kāshān, and the town of Fin, future multidisciplinary excavations should be designed to carefully investigate the archeoseismic and environmental indicators left in the archeological record as well as in the limited wetlands. Valuable data about ancient earthquakes and climate effects can be obtained by combining archeological, geological, and environmental studies, which ultimately will provide specific insight into the earthquake recurrence period along the Kāshān fault and a greater understanding of the socio-economic and political context of the area during ancient times.

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